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Factorization breaking in diffractive dijet production

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Abstract

We study diffractive hard dijet production, with one or two rapidity gaps, at high energies. We emphasize that both hard and Regge factorization are broken in these processes. We show that a multi-Pomeron-exchange model for screening effects gives a specific pattern for the breakdown of factorization, which is in good agreement with diffractive dijet data collected at the Tevatron.

The investigation of diffractive processes at high energies gives important information on the structure of hadrons and their interaction mechanisms. Hard diffractive processes, such as the diffractive production of dijets, allow the study of the interplay of small- and large-distance dynamics within QCD. The existence of a hard scale provides the normalization of the Born term diagram, which is shown for single-diffractive dissociation in Fig. 1(a) and for the double-diffractive process¹ in Fig. 1(b). These processes are respectively characterized by the existence of one and two large rapidity gaps, each of which is represented by Pomeron exchange. At high energies, there are important contributions from unitarization effects. In the t channel Reggeon framework, these effects are described by multi-Pomeron exchange diagrams,

¹Here by double-diffractive we mean a process with two rapidity gaps which, at high energies, corresponds to double-Pomeron-exchange.

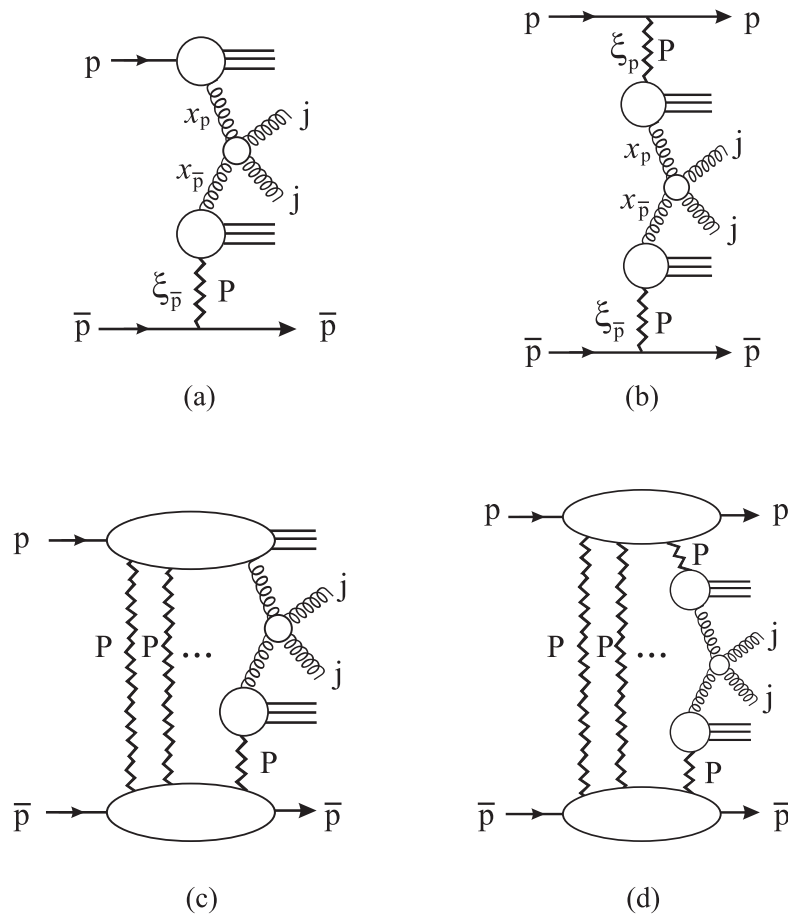


Figure 1: (a,b) The Born diagrams for diffractive dijet production in high energy $p\bar{p}$ collisions with one, two rapidity gaps indicated by Pomeron, P , exchange. (c,d) The multi-Pomeron exchange contributions to the above processes, where the upper and lower blobs encapsulate all possible Pomeron permutations.

Figs 1(c),(d). Such diagrams lead to a strong violation of both Regge and hard factorization, which were valid for the Born diagrams of Figs. 1(a),(b).

As has been known for a long time (see, for example, [1]), factorization does not necessarily hold for diffractive production processes; for recent studies see Refs. [2, 3, 4] and references therein. The suppression of the single-Pomeron Born cross section due to the multi-Pomeron contributions² depends, in general, on the particular hard process. At the Tevatron energy, $\sqrt{s} = 1.8$ TeV, the suppression is in the range 0.05–0.2 [6, 7, 8, 2]. In fact, a computation of this effect was found to give a quantitative understanding [2] of the experimentally-observed

²Another approach to the phenomenon of factorization breaking has been proposed by Goulianos within the so-called gap probability renormalization model, see [5] and references therein.

suppression of the single diffractive dijet cross sections at the Tevatron [9] as compared to the predictions based on HERA results [10]. The comparison relies on the partonic distributions in the Pomeron determined from HERA data. These parton densities have some uncertainty (especially for the gluonic content of the Pomeron). Interestingly, when the new fit to the H1 diffractive data [11] is used in the approach of Ref. [2], even better agreement with the CDF Tevatron data [9] is achieved [12].

Nowadays diffractive processes are attracting more attention as a way of extending the physics programme at proton colliders, including novel ways of searching for New Physics; see, for example, [13, 14, 15]. Clearly, the correct treatment of the screening effects is crucial for the reliability of the theoretical predictions of the cross sections for these diffractive processes. As mentioned above, some tests of the mechanism of diffractive dijet production have been made [16, 2, 12], but further, model-independent, checks are highly desirable.

Double-diffractive dijet production provides the attractive possibility to test factorization, in a parameter-free way, using only data from hadronic collisions. This allows an important consistency test of the whole approach. Indeed, a test of factorization has been performed recently by the CDF collaboration at $\sqrt{s} = 1.8$ TeV [17]. The data of interest are dijet production in single-diffractive dissociation (SD), Figs. 1(a),(c), and in the double-Pomeron-exchange (DP) process, Figs. 1(b),(d). The distributions of the partons³ which collide in Figs. 1(a),(c) to produce the dijet system may be taken as the effective densities

$$f_a(x) \equiv g_a(x) + \frac{4}{9}q_a(x), \quad (1)$$

since the hard subprocess is dominated by gluon t channel exchange. Here $g(x)$ and $q(x)$ denote the gluon and the sum of quark, antiquark densities, and $4/9$ is the appropriate colour factor. The subscript $a = p$ (\bar{p}) or P indicates whether the ‘gluon’ belongs to the proton (antiproton) or the Pomeron, as seen, for example, in the upper and lower parts of Fig. 1(a) respectively.

Following [17], we consider first the ratio of SD dijet production to non-diffractive (ND) dijet production. Then, in the ratio of the cross sections (for the same kinematical characteristics of jets, $E_{T_i} > 7$ GeV), the quantity $f_p(x_i)\sigma_{jj}(\eta_{j1}, \eta_{j2}, E_{T1}, E_{T2})$ cancels out, where σ_{jj} is the partonic cross section to produce dijets with pseudorapidities η_{j1}, η_{j2} and transverse energies E_{T1}, E_{T2} . Moreover the two processes are measured by the same detector so, in the ratio, experimental uncertainties are reduced. Allowing for the above cancellation, the ratio can be written in the form

$$R_{\text{ND}}^{\text{SD}} \equiv \frac{\sigma_{jj}^{\text{SD}}}{\sigma_{jj}^{\text{ND}}} = \frac{F_P(\xi_{\bar{p}})f_P(\beta)\beta}{f_{\bar{p}}(x_{\bar{p}})x_{\bar{p}}} S_1, \quad (2)$$

where $F_P(\xi_{\bar{p}})$ is the Pomeron ‘flux factor’, $\xi_{\bar{p}}$ is the fraction of the initial momentum carried by the Pomeron (experimentally $\xi_{\bar{p}} < 0.1$), $f_P(\beta)$ is the effective distribution of partons in the Pomeron and $x_{\bar{p}} = \beta\xi_{\bar{p}}$. The suppression factor S_1 , which, following Bjorken [19], is often called

³The Born diagrams of Figs. 1(a),(b) correspond to the Ingleman–Schlein conjecture [18].

the survival probability, accounts for the screening effects caused by diagrams of the type shown in Fig. 1(c). It is normalized so that $S_1 \equiv 1$ for the Born diagram of Fig. 1(a).

In order to provide a quantitative check of the ‘factorization-violating’ suppression factors, it is possible to remove, to a large extent, the uncertainties associated with the Pomeron flux factor and the parton distributions and detector effects, by studying a second ratio of measured cross sections. Considering the ratio of cross sections for dijet production by the double-Pomeron-exchange (DP) and the single diffractive (SD) processes, we have

$$R_{\text{SD}}^{\text{DP}} \equiv \frac{\sigma_{jj}^{\text{DP}}}{\sigma_{jj}^{\text{SD}}} = \frac{F_P(\xi_p) f_P(\beta_1) \beta_1}{f_p(x_p) x_p} \frac{S_2}{S_1}, \quad (3)$$

where S_2 is the suppression factor for the DP process (in general $S_2 \neq S_1$). Then the ratio of the two ratios, (2) and (3), becomes

$$D = \frac{R_{\text{ND}}^{\text{SD}}}{R_{\text{SD}}^{\text{DP}}} = \frac{F_P(\xi_{\bar{p}}) f_P(\beta) \beta}{F_P(\xi_p) f_P(\beta_1) \beta_1} \frac{f_p(x_p) x_p}{f_{\bar{p}}(x_{\bar{p}}) x_{\bar{p}}} \frac{S_1^2}{S_2}. \quad (4)$$

In the case when $\xi_{\bar{p}} = \xi_p$ and $\beta = \beta_1$ ($x_{\bar{p}} = x_p$), the double ratio becomes

$$D = \frac{S_1^2}{S_2}. \quad (5)$$

If there were no multi-Pomeron effects ($S_1 = S_2 = 1$) then $D = 1$. Thus a deviation of D from unity would signal a failure of factorization. We emphasize that, although we use Regge factorization (with the cross sections written as products of flux factors and the corresponding partonic distributions), the result is practically insensitive to this assumption. The breakdown of factorization for hard diffractive processes is naturally expected in QCD; see, for example, [20, 2, 4].

To make a quantitative evaluation of the ratio D we use the model predictions of Ref. [7] for the multi-Pomeron screening effects, where the suppression factors S_i were calculated for a range of hard diffractive processes at the various pp (and $p\bar{p}$) collider energies. For our processes at $\sqrt{s} = 1.8$ TeV they were found to be

$$S_1 = 0.10, \quad S_2 = 0.05. \quad (6)$$

The difference between S_1 and S_2 is due to the difference in the impact parameter profiles for the processes of diagrams 1(a) and 1(b). Thus the prediction of the model is $D = 0.2$. It was emphasized in Ref. [2] that the suppression factor⁴ S_1 can depend also on $x_{\bar{p}}$ and β . When more precise data become available, these dependences can be taken into account. However, in the kinematical range of the CDF measurement [17], the average value of S_1 turns out to be very close to 0.10.

⁴There may also be a β dependence of the suppression factor arising from QCD radiative effects; see, for example, Ref. [20]. However, for the relevant CDF kinematics with β not close to 1, this dependence is not significant and, moreover, is essentially cancelled out in the ratio (4).

The experimental value for the double ratio obtained by the CDF Collaboration [17] is $D = 0.19 \pm 0.07$, in good agreement with the theoretical prediction. It clearly demonstrates the presence of factorization breaking and the importance of unitarization effects due to multi-Pomeron exchanges.

It is worth commenting briefly on one aspect of the experimental determination of the ratio D [17]. The range of $\xi_{\bar{p}}$ covered in the CDF measurements was $0.035 < \xi_{\bar{p}} < 0.095$, while ξ_p was in the interval $0.01 < \xi_p < 0.03$. It was therefore necessary to extrapolate the second ratio R_{SD}^{DP} in $\xi_{\bar{p}}$ to the value $\xi_{\bar{p}} = 0.02$ in order to have the same values of ξ_i in Eq. (4). This was done on the assumption that this ratio is independent of $\xi_{\bar{p}}$ (for a given $x_{\bar{p}}$), as was in fact seen in the data in the observed range of $\xi_{\bar{p}}$. This assumption is confirmed by the model of Ref. [2], where a detailed description of the CDF data on SD dijet production was performed. It was shown that the $\xi_{\bar{p}}$ -dependence, arising from the Pomeron and secondary exchange contributions in the region $0.01 \leq \xi_{\bar{p}} \leq 0.1$, can be approximated by $1/\xi_{\bar{p}}^{n_1}$ with $n_1 \simeq 1$. Moreover, the β -dependence in the region $\beta < 0.2$ is also close to $1/\beta^{n_2}$ with $n_2 \simeq 1$; a behaviour which well summarizes several contributing β behaviours [2]. Thus, the total dependence on β and $\xi_{\bar{p}}$ is $1/\beta\xi_{\bar{p}} = 1/x_{\bar{p}}$. Therefore, for fixed $x_{\bar{p}}$ there is no dependence on $\xi_{\bar{p}}$. The approximate equality of the values of n_1 and n_2 may not hold at very small $\xi_{\bar{p}}$ or at much higher energies [2].

In conclusion, we have demonstrated that a theoretical framework, which takes into account unitarization effects due to multi-Pomeron exchanges, predicts a substantial breakdown of factorization in hard diffractive processes. The multi-Pomeron effects suppress the Born cross section by *different* factors for *different* diffractive processes, due to the *different* impact parameter profiles of the various cross sections. We have proposed a check of the factorization-violating suppression factors which depends only on *measured* cross sections at the Tevatron, namely the cross sections for dijet production in single diffractive and double-Pomeron-exchange processes. The prediction and the data are in good agreement. A detailed comparison, along the lines proposed, of forthcoming precision dijet data from the Tevatron or LHC will be very informative.

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References

- [1] A.B. Kaidalov, Phys. Rep. **50** (1979) 157;
Ya.I. Azimov, V.A. Khoze, E.M. Levin and M.G. Ryskin, Nucl. Phys. **B89** (1975) 508.

- [2] A.B. Kaidalov, V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. **C21** (2001) 521.
- [3] A. Bialas, Acta Phys. Polon. **B33** (2002) 3523.
- [4] J. Collins, J. Phys. **G28** (2002) 1069.
- [5] K. Goulianos, J. Phys. **G26** (2000) 716; [arXiv:hep-ph/0203141](#).
- [6] E. Gotsman, E. Levin and U. Maor, Phys. Rev. **D60** (1999) 094011 and references therein.
- [7] V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. **C18** (2000) 167; Nucl. Phys. (Proc. Suppl.) **B99** (2001) 213.
- [8] M.M. Block and F. Halzen, Phys. Rev. **D63** (2001) 114004.
- [9] CDF Collaboration: T. Affolder et al., Phys. Rev. Lett. **84** (2000) 5043.
- [10] H1 Collaboration: T. Ahmed et al., Phys. Lett. **B348** (1995) 681;
C. Adloff et al., Z. Phys. **C76** (1997) 613.
- [11] F.-P. Schilling, [arXiv:hep-ex/0210027](#).
- [12] V.A. Khoze, A.D. Martin and M.G. Ryskin, [arXiv:hep-ph/0210094](#).
- [13] M.G. Albrow and A. Rostovtsev, [arXiv:hep-ph/0009336](#); and references therein.
- [14] V.A. Khoze, A.D. Martin and M.G. Ryskin, Eur. Phys. J. **C23** (2002) 311.
- [15] A. De Roeck, V.A. Khoze, A.D. Martin, R. Orava and M.G. Ryskin, Eur. Phys. J. **C25** (2002) 391.
- [16] V.A. Khoze, A.D. Martin and M.G. Ryskin, [arXiv:hep-ph/0006005](#), in *Proc. of 8th Int. Workshop on Deep Inelastic Scattering and QCD (DIS2000)*, Liverpool, eds. J. Gracey and T. Greenshaw (World Scientific, 2001), p.592.
- [17] CDF Collaboration: T. Affolder et al., Phys. Rev. Lett. **85** (2000) 4215.
- [18] G. Ingelman and P.E. Schlein, Phys. Lett. **B152** (1985) 256.
- [19] J.D. Bjorken, Int. J. Mod. Phys. **A7** (1992) 4189, Phys. Rev. **D47** (1993) 101.
- [20] A.D. Martin, M.G. Ryskin and V.A. Khoze, Phys. Rev. **D56** (1997) 5867.
V.A. Khoze, A.D. Martin and M.G. Ryskin, Phys. Lett. **B502** (2001) 87.